

Volume of individual internodes of sugarcane stalks

T.R. Sinclair^{a,*}, R.A. Gilbert^b, R.E. Perdomo^c, J.M. Shine^d, G. Powell^c, G. Montes^c

^aUSDA-ARS, Agronomy Physiology Laboratory, P.O. Box 110965, University of Florida, Gainesville, FL 32611-0965, USA

^bEverglades Research and Education Center, 3200 E. Palm Beach Rd., Belle Glade, FL 33430-4702, USA

^cFlorida Crystals Corporation, P.O. Box 86, South Bay, FL 33493, USA

^dSugar Cane Growers Cooperative, P.O. Box 666, Belle Glade, FL 33430-0666, USA

Received 21 January 2004; received in revised form 27 June 2004; accepted 4 July 2004

Abstract

Sugarcane (*Saccharum* spp.) is rather unusual among field crops in that it is not the seed that is of economic value, but rather the stalk. Sucrose is extracted from the large stalks that are produced by sugarcane plants. Considering their economic value, it is rather surprisingly that there is very little information concerning the development and size of the individual internodes over the length of sugarcane stalks. The objective of this study was to document internode volume over the sugarcane stalk of four cultivars and to observe changes in individual internode volume later in the growing season and in response to lodging. When harvested in August, the size of the internodes varied in a continuous manner along the stalk with the largest internode occurring at the bottom of the plant at approximately internode #15. One cultivar (CP80-1743) had much less of a decrease in internode volume below internode #15 than the other cultivars, indicating that growth was more concentrated in the lower internodes of this cultivar. Since the internode volume diminished as the apex was approached, much of the harvested material was concentrated in the bottom nodes. Comparison of a mid-season harvest (August) and a final harvest (January) indicated both that additional internodes were added to the stalk and that the size of all internodes increased. That is, plant growth was distributed all along the stalk and not focused on one particular zone. Similarly, the negative impact of plant lodging was uniformly distributed over the entire stalk, although there appeared to be differences in cultivars in the extent to which the growth of the stalk was decreased.

Published by Elsevier B.V.

Keywords: Sugarcane; Internode volume; Stalk growth; Lodging

1. Introduction

Reproductive tissue is harvested as the economic product in nearly all field crops but this is not the case

in sugarcane (*Saccharum* spp.). In sugarcane, the stalks are the harvested tissue and stalk size has a major influence on yield. It is surprising, therefore, that there has been virtually no research reported on the variation in size of individual stalk internodes with position on the stalk and with crop growth.

Lingle (1999) tracked the development of two internodes of sugarcane from near the beginning of

* Corresponding author. Tel.: +1 352 392 6180;

fax: +1 352 392 6139.

E-mail address: trsinc1@ifas.ufl.edu (T.R. Sinclair).

their elongation (internode approximately 10-mm long). The first internode was identified in July and the second in September on a plant crop and in the subsequent year on the first ratoon crop grown at Mercedes, TX, USA. Average duration of internode length increase across seven cultivars was cumulative 380 °C assuming a base temperature of 18 °C. That is, if daily mean temperature was 28 °C, the internodes would increase their length over a period of 38 days. Lingle (1999) found that dry weight of the internodes, however, increased over a much longer period. By the time internode length stopped increasing, the dry weight of the internodes was still less than half its final weight. Approximately, cumulative 800 °C was required to reach final dry weight, or in the case of a 28 °C mean daily temperature a total of 80 days was required. It was not documented explicitly whether the change in internode weight after elongation ceased was by an increase in internode radius or mass density.

This research was designed to obtain basic observations on variations in internode volume over the entire length of sugarcane stalks. In particular, data were obtained to document differences in sugarcane internode volume with position in the stalk between mid-season and the final harvest stage. Based on the data of Lingle (1999) it was hypothesized that the volume of internodes near the base of the stalk would be fixed by mid-season and stalk growth until harvest would be reflected in volume changes in the volume of mid-stalk internodes. Since some of the plants had lodged between the two harvest dates, both erect and lodged plants were harvested at the final harvest to document the consequences of the lodging on internode volume. The internode response to lodging was hypothesized to be concentrated in those internodes involved with stalk bending that allowed the apical portion of the stalk to recover to a more vertical position following lodging.

2. Materials and methods

2.1. Field design

Internode volume was measured on four commercial cultivars, which were included in a study of plant development (Sinclair et al., 2004). These cultivars were CP72-2086 (Miller et al., 1984), CP80-1743

(Deren et al., 1991), CP88-1762 (Tai et al., 1997) and CP89-2143 (Glaz et al., 2000). The cultivars were grown at two locations in the Everglades Agricultural Area of south Florida. One location was at the Everglades Research and Education Center (EREC) (26°39'N, 80°38'W) and the other on a Florida Crystals Corp. (FCC) field site about 36 km south of Lake Okeechobee (26°26'N, 80°31'W). The soil at each location was a Lauderhill muck (euic, hyperthermic Lithic Haplosaprist).

The experimental design was the same at both locations: a randomized block with six replications. The seed-cane pieces were planted into rows on 24 November 2000 at EREC and on 1 December 2000 at FCC. Each replicate of each cultivar consisted of five rows spaced 1.5-m apart and 10-m long. After completing observations on the plant crop, all plants were cut and removed from the plots on 22 January 2002. The ratoon crop then grew from the stubble. No N fertilizer was applied to the soil during these experiments because the high organic matter of the soil provided the required N. The amounts of P/K applied were 0/0, 63/142, 50/246, and 50/222 kg ha⁻¹ prior to the plant and ratoon crops at EREC and the plant and ratoon crops at FCC, respectively. The plots were maintained in a well-watered condition by maintaining the water depth in canals adjacent to the fields at approximately 1 m.

2.2. Observations

Volumes of individual internodes were measured on both plant crops (2001) and first-ratoon crops (2002). The plants on which these data were recorded were actually tagged shortly after plant emergence in both years as part of the study to monitor leaf area development (Sinclair et al., 2004). Ten plants in each replicate of each cultivar were tagged at the same time. Since the node number was tracked for the identification of leaves, the number of each internode was also identifiable. The internode below each node was assigned the same number as the node.

On 21–22 August 2001 and 22–23 August 2002, all plants were harvested by cutting the stalk at the soil surface. Since the bottom-most internodes were very short and below the soil surface (at least internodes #1 to #5), the very bottom internodes of the stalk were not measured. All leaves were removed from the stalk and

the length and diameter of each internode were recorded. The internode length was measured to the nearest millimeter as the distance between adjacent nodes. The internode diameter was measured using calipers to the nearest 0.1 mm at the midpoint of the internode. The volume of each internode was calculated by assuming a cylindrical shape for the internode. After measuring all internodes, the stalk material was dried in a 50 °C oven to obtain total stalk dry weight for each plant.

Internode volumes were also determined just before the final harvest of the plots on 13 and 14 January 2003. By this time, some plants of each plot had lodged and the top portions of these lodged plants had recovered to nearly a vertical position. Harvests were done from each plot of three erect plants and three lodged plants. Since the plants harvested in January had not been tagged at a young age, it was not possible to assign exact internode numbers. An approximation was done based on the internode volume data itself. The August results indicated a clear maximum volume at specific internodes. Consistent with the hypothesis that the bottom nodes were not expected to increase greatly in volume following the August harvest, the internode with the maximum volume identified in August was used to assign internode numbers in January.

In addition to internode length and diameter measurements, the stalk curvature of the lodged plants was also measured. The curvature resulted from uneven growth on opposing sides at individual nodes. The angle resulting from the asymmetrical node growth was measured as the angle from linearity of the two internodes on either side of the node. The angles were measured to the nearest 1° using protractors. The results of these measurements are presented as cumulative curvature with increasing internode number.

3. Results

3.1. Internode volume within stalk

There was a fairly consistent pattern in relative internode volume along the stalk among all four cultivars at the August sampling of the plant crop (Fig. 1). The internode with maximum volume within

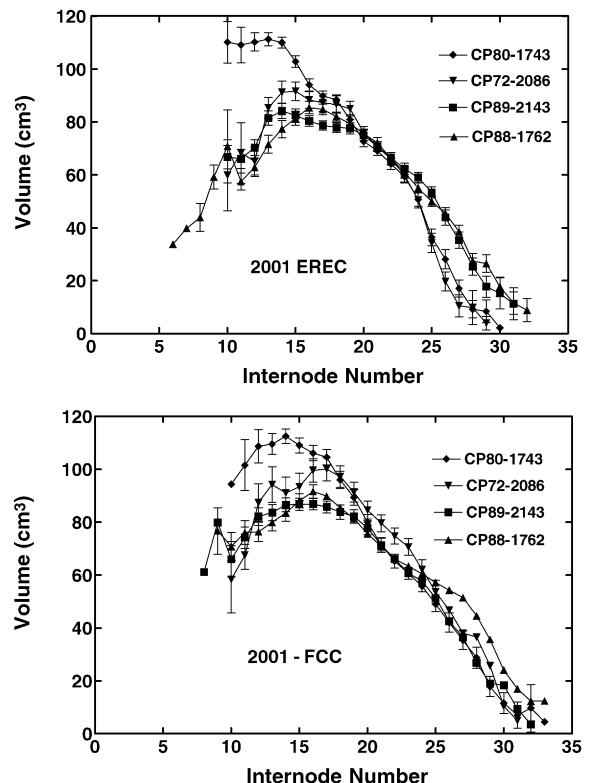


Fig. 1. Individual internode volumes of the plant crop of four sugarcane cultivars harvested in August 2001 at the Everglades Research and Education Center (EREC) and Florida Crystals Corporation (FCC). Vertical bars are the standard error for the mean for those cases where the value is greater than the size of the symbol.

a cultivar at the August harvest was stable between the two locations. The cultivars differed slightly in the internode of maximum volume in that the largest internode was #14 for CP80-1743, #15 for CP89-2143, and #16 for CP88-1762 and CP72-2086. These positions of the internodes with maximum volume were used to define internode number of those plants harvested in January 2003.

There were no large differences in pattern of volume distribution or absolute volume among cultivars except that CP80-1743 tended to have much larger volume than other cultivars at internodes #10 to #15. The volume of internodes greater than #25 decreased substantially in all cultivars and contributed little to the overall volume of the stalks. There were no significant differences in total stalk dry weight among cultivars (data not shown).

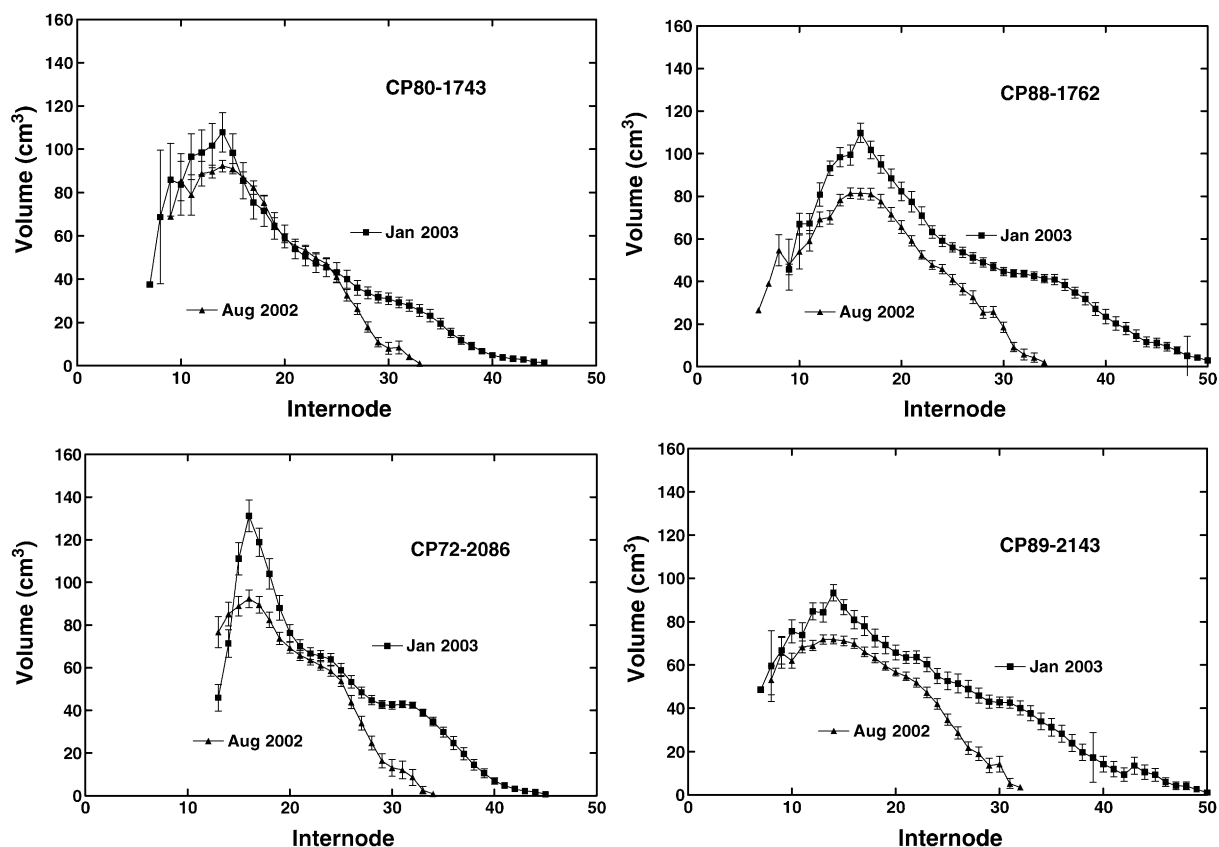


Fig. 2. Individual internode volumes of the ratoon crop of four sugarcane cultivars grown at the Everglades Research and Education Center (EREC) and harvested in August 2002 and January 2003. Vertical bars are the standard error of the mean for those cases where the value is greater than the size of the symbol.

The pattern of internode volume for the August harvest of the ratoon crop at the two locations (Figs. 2 and 3) was much the same as the plant crop. There was a maximum internode volume at about internode #15 with a gradual decline in volume with higher internodes. A 'shoulder' in the decline in internode volume at about internode #20 to #24 was apparent in the data for the plants at FCC (Fig. 3).

3.2. Final harvest internode volume

The pattern of internode volume along the stalk in January was much the same as observed in the August harvests (Figs. 1–3). Of course, by definition the maximum internode volume was at approximately internode #15. The total number of internodes at

the final harvest had increased to roughly 50 with a consistent pattern of decreasing internode volume with ascending internode number above the internode of maximum volume.

The differences in internode volumes measured in August as compared to the January harvest of cultivar CP80-1743 at EREC (Fig. 2) was as hypothesized. That is, internode volumes below about internode #25 in the August harvests and were little changed between the August and January harvests. Following the August harvest, changes in stalk volume were mainly attributed to increases in internode volume above about internode #25. At FCC, however, increases in the volume of the lower internodes of CP80-1743 were found but the increase tended to be less than observed in the other three cultivars (Fig. 3).

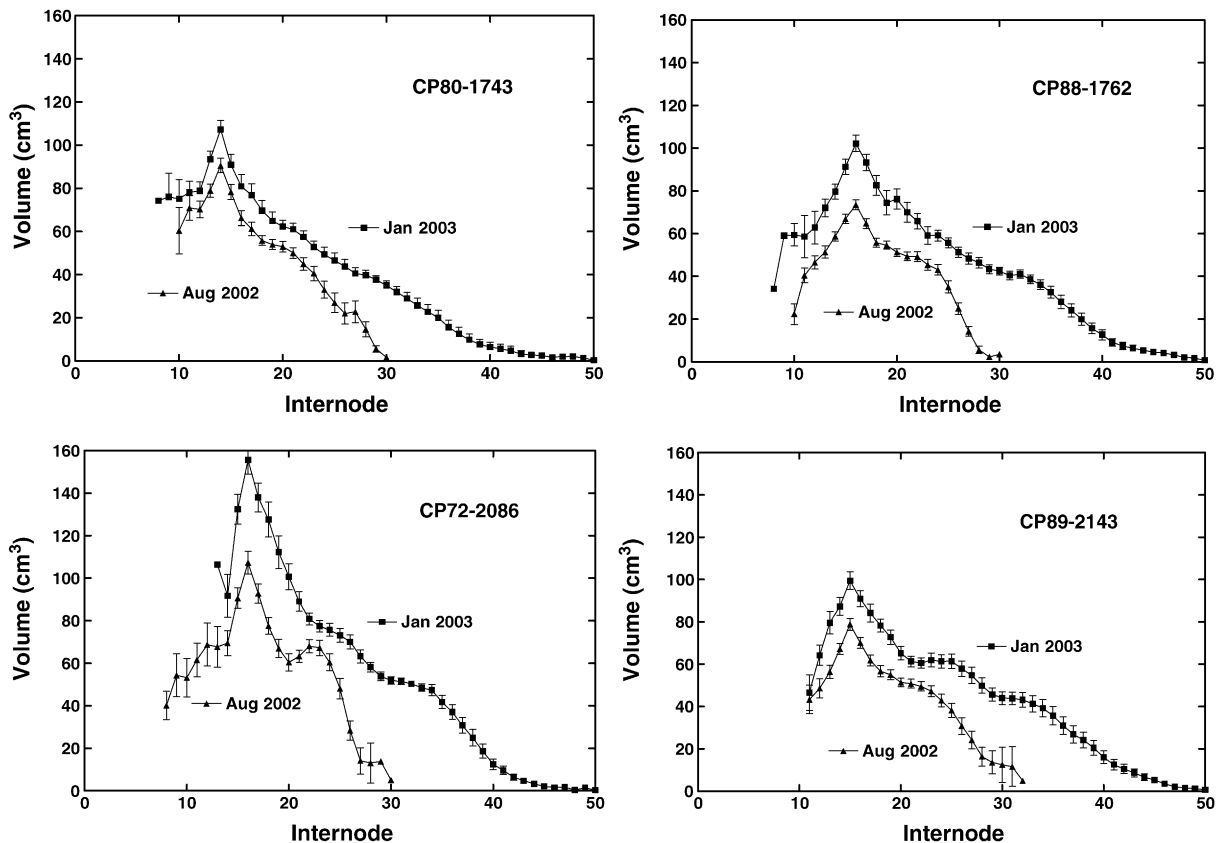


Fig. 3. Individual internode volumes of the ratoon crop of four sugarcane cultivars grown at Florida Crystals Corporation (FCC) and harvested in August 2002 and January 2003. Vertical bars are the standard error of the mean for those cases where the value is greater than the size of the symbol.

In contrast to CP80-1743, the other three cultivars had some increases in internode volume at virtually all positions along the stalk at the January harvest as compared to the August harvest (Figs. 2 and 3). There appeared to be a fairly uniform increase in volume of all internodes at positions less than roughly #25 between August and January. Above #25 the increase in internode size between August and January was much greater than lower internodes and, of course, internodes greater than about #32 were added between the two harvest dates.

The differences in internode volume for the bottom internodes observed between August and January were a result of differences in internode diameter. Internode length of these bottom internodes did not change following the August harvest (data not shown)

consistent with the results of Lingle (1999), so expansion of internode diameter accounted for the observed differences in volume between the two harvest dates. Of course, volume is dependent on the radius squared so the greater volume obtained in January was not linearly dependent on an increases in diameter. For example, a 20% greater internode volume at the January harvest resulted from only a 10% increase in internode diameter as compared to an internode that had a 3-cm diameter in August.

3.3. Lodging and internode volume

Those plants selected as being lodged had curvature near the middle of the stalk causing the top part of the plant to be in a more vertical position. In particular,

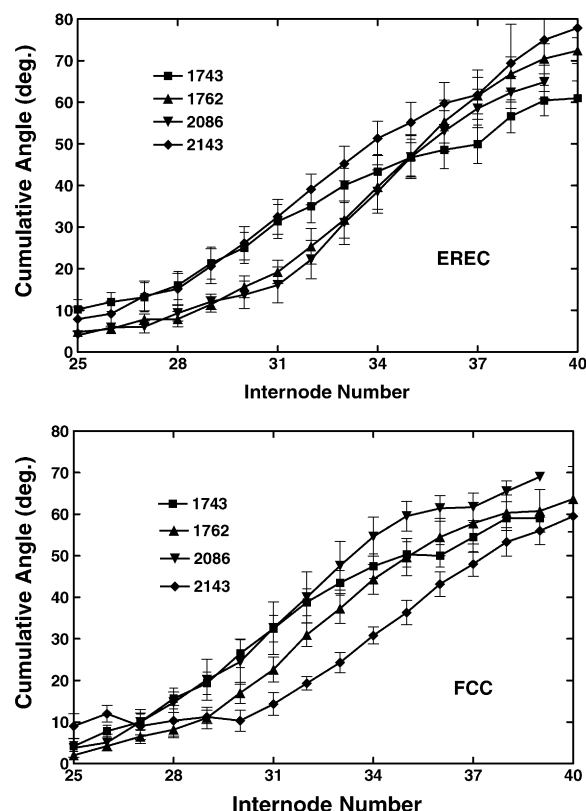


Fig. 4. Cumulative angle of curvature at each node from the bottom of the stalk towards the top. Data were obtained for four cultivars harvested in January 2003 at the Everglades Research and Education Center (EREC) and Florida Crystals Corporation (FCC). Vertical bars are the standard error of the mean for those cases where the value is greater than the size of the symbol.

the curvature was found at approximately nodes #28 to #38 (Fig. 4). The mean cumulative curvature was about 60° – 75° . A few individual plants had the top portion of their stalks fully erect. There was no obvious difference in cumulative curvature among cultivars.

There was no support for the original hypothesis that internode volume within the zone of curvature would be influenced to the greatest amount by lodging. The distribution of internode volume along the stalk was unchanged as a result of the lodging (Figs. 5 and 6). In fact, there was no change in internode volume at any position on the stalk in several cases. Cultivars CP80-1743 and CP89-2143 exhibited little or no difference in internode volume as a result of lodging

at both locations. CP88-1762 had a decrease in internode volume at both locations, but the decrease was spread fairly uniformly over the entire stalk. The results with CP72-2086 were inconsistent since at the EREC location there was no difference between the erect and lodged plants (Fig. 5), while at the FCC location there was a marked decrease in internode volume all along the stalk (Fig. 6).

4. Discussion

The data collected on these four cultivars indicated a fairly consistent pattern in internode volume along the stalks of sugarcane regardless of cultivar and time of harvest. Bottom internodes accounted for much of the stalk volume with the largest internode being at about internode #15. The volume of the internodes decreased in a continuous manner above the largest internode so that the top-most internodes contributed very little to the overall volume of the stalk.

Cultivar CP80-1743 had a slightly different pattern in internode volume in that the internodes below the internode with maximum volume tended to be larger than measured for other cultivars. These large internodes at the base of CP80-1743 indicated that special attention needs to be given to the commercial harvesting of this cultivar so that the stalks are cut near the soil surface to maximize yield. It is interesting that cultivar CP80-1743 is now the most widely grown cultivar in the Everglades Agricultural area largely because of its superior ratooning performance. This may reflect the fact that following harvest large internodes of CP80-1743 are left in the stool and these internodes may provide a large nutrient reserve to support crop regrowth.

Except for one cultivar, volume differences were observed between the August and January harvests in all internodes along the stalk including the bottom internodes that were thought to be 'mature'. The increases in volume were associated with increases in internode diameter since there was no increase in internode length at the bottom of the stalk. A key question, however, is whether the differences in the internode volume of the bottom internodes between the two harvest dates really represented growth or only a difference in the population of stalks sampled at the two dates. The August harvests were plants identified

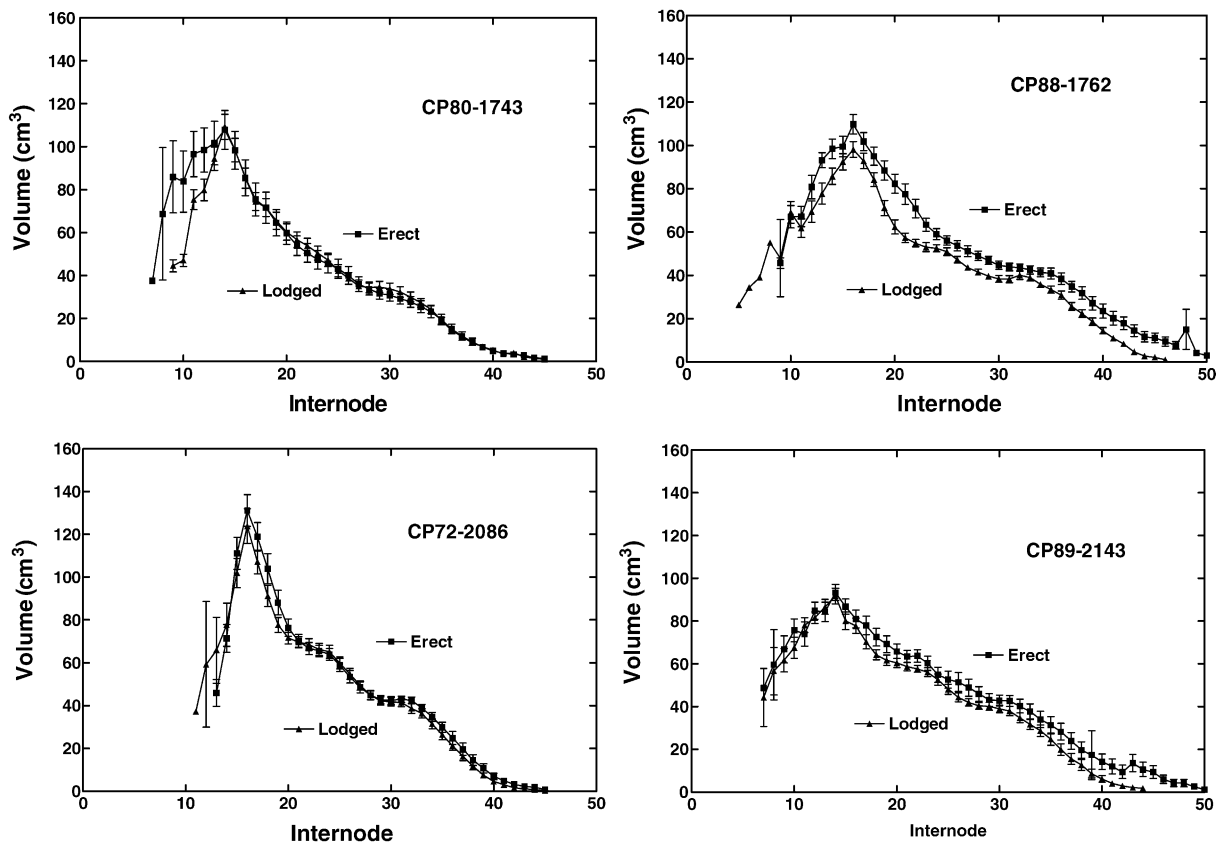


Fig. 5. Individual internode volumes of erect and lodged plants harvested in January 2003 from the ratoon crop of four sugarcane cultivars grown at the Everglades Research and Education Center (EREC). Vertical bars are the standard error of the mean for those cases where the value is greater than the size of the symbol.

at a very early stage of crop development, while the plants harvested in January were selected from the population of plants that had competed and survived until January. Therefore, there may be a bias in selecting more successful plants in January, although the similarity of volumes of the bottom internodes of C80-1743 at EREC (Fig. 2) indicated that such a bias did not exist in this one case at least.

Regardless of the basis of the difference in the volumes between the two harvest dates, these results showed that differences in volume of approximately internode #25 and less between August and January were based on differences in internode diameter. This is consistent with the observations of Lingle (1999) that internode length is fixed relatively early in internode development. The regulation and flexibility of

internode diameter may be a key point of interest in understanding the growth capabilities along sugarcane stalks. Sustained increases in internode volume, which seem necessary to maintain the observed stability in relative distribution of internode volume along the stalk, raises an interesting challenge in the mechanics of expansion of internode diameter.

A coordinated increase in internode volume all along the stalk also raises an additional question about regulation of the distribution of new assimilate along the stalk. More-or-less uniform increase in internode volume along the length of the stalk implies a fairly high degree of integrated regulation in growth among internodes in order to achieve a consistent pattern in internode volume along the stalk. These data do not support a simple model of simply putting current

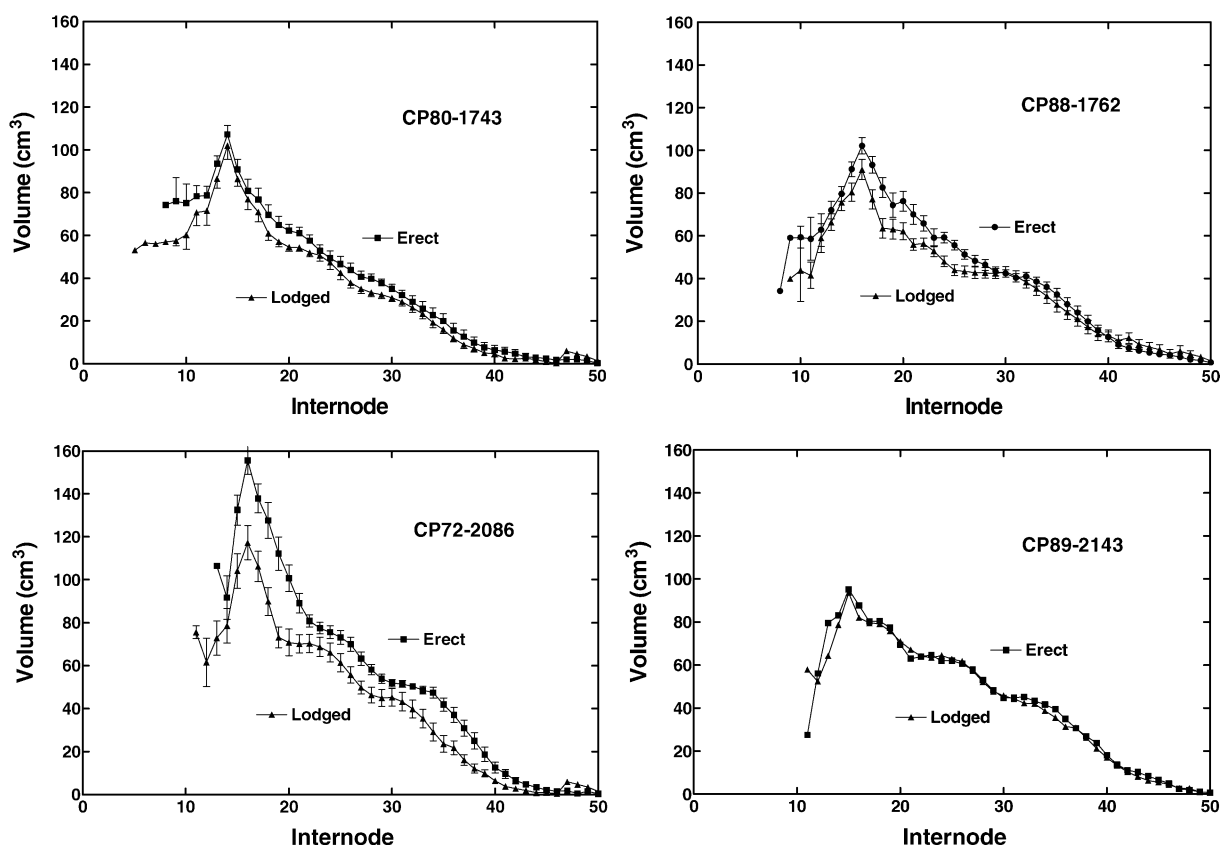


Fig. 6. Individual internode volumes of erect and lodged plants harvested in January 2003 from the ratoon crop of four sugarcane cultivars grown at Florida Crystals Corporation (FCC). Vertical bars are the standard error of the mean for those cases where the value is greater than the size of the symbol.

photosynthate in the internodes nearest to the leaves as plants grow. It appears there must be active regulation to distribute photosynthate in a more-or-less uniform manner along the stalk.

Also, the hypothesis that lodging stress would be reflected in the volume of individual internodes associated with the zone of stalk curvature was rejected. In those cases where lodging resulted in decreased internode volume, the decrease was spread nearly uniformly across all internodes on the plant. Cultivar CP88-1762 seemed to be the most sensitive to lodging of the four tested cultivars as evidenced by differences in internode volume between lodged and erect plants. On the other hand, there were cases where internode volume did not appear to be sensitive to the lodging stress. Cultivar CP80-1743, in particular, seemed to be less sensitive to lodging stress. These results on the

volume of individual internodes are consistent with those of Singh et al. (2002) in which it was found that lodging in two sugarcane cultivars resulted in little change in the dry mass of individual live stalks. In their study, the loss of sugar yield per unit land area associated with lodging was a consequence of decreased stalk sugar concentration and decreased number of live stalks.

Overall, these results indicated that growth of the sugarcane stalk is a well-coordinated process in which nearly all internodes are involved. The volume changes of individual internodes seem to be well coordinated to give a consistent pattern of relative internode volume along the sugarcane stalk. Comparisons of plants at differing ages and between plants suffering lodging stress indicated the same relative distribution of internode volume is maintained along

the stalk. The intriguing observations that CP80-1743 had relatively larger internodes at the base of the stalk and that internode volume was changed little as a result of lodging offer possible explanations in regards to its commercial success.

Acknowledgments

The authors gratefully acknowledge the dedicated contributions to this study of Barney Eiland, Florida Crystals Corporation; Lee Liang, University of Florida; Ron Gosa, Florida Sugar Cane League; and Robert Taylor, Sugar Cane Growers Cooperative of Florida. Their participation in this research was essential in plot management, data collection, and data analysis.

References

- Deren, C.W., Glaz, B., Tai, P.Y.P., Miller, J.D., Shine Jr., J.M., 1991. Registration of CP80-1743 sugarcane. *Crop Sci.* 31, 235–236.
- Glaz, B., Miller, J.D., Deren, C.W., Tai, P.Y.P., Shine Jr., J.M., Comstock, J.C., 2000. Registration of CP89-2143 sugarcane. *Crop Sci.* 40, 577.
- Lingle, S.E., 1999. Sugar metabolism during growth and development in sugarcane internodes. *Crop Sci.* 39, 480–486.
- Miller, J.D., Tai, P.Y.P., Glaz, B., Dean, J.L., Kang, M.S., 1984. Registration of CP72-2086 sugarcane. *Crop Sci.* 24, 210.
- Sinclair, T.R., Gilbert, R.A., Perdomo, R.E., Shine Jr., J.M., Powell, G., Montes, G., 2004. Sugarcane leaf area development under field conditions in Florida, USA. *Field Crops Res.* 88, 171–178.
- Singh, G., Chapman, S.C., Allen, P.A., Lawn, R.J., 2002. Lodging reduces sucrose accumulation of sugarcane in the wet and dry tropics. *Aust. J. Agric. Res.* 53, 1183–1195.
- Tai, P.Y.P., Shine Jr., J.M., Deren, C.W., Glaz, B., Miller, J.D., Comstock, J.C., 1997. Registration of CP88-1762 sugarcane. *Crop Sci.* 37, 1388.